A CONTINUING SYSTEMATIC PROGRAM ON TABLES OF THERMOPHYSICAL PROPERTIES OF MATERIALS

C. Y. HO

Thermophysical Properties Research Center
Purdue University

TECHNICAL REPORT AFML-TR-70-92

JUNE 1970

This document has been approved for public release and sale; its distribution is unlimited.

Distribution Statement A:
Approved for public release;
distribution is unlimited.

AIR FORCE MATERIALS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

1400 - June 1970 - CO455 - 124-2732

A CONTINUING SYSTEMATIC PROGRAM ON TABLES OF THERMOPHYSICAL PROPERTIES OF MATERIALS

C. Y. HO

FOREWORD

This report was prepared by the Thermophysical Properties Research Center (TPRC), Purdue University, West Lafayette, Indiana, under USAF Contract No. F33615-68-1229, "Scientific Documentation and Preparation of Data Tables on Thermophysical Properties." This continuing program is performed under Project No. 8975, Materials Information Analysis Center, Task No. 897502, Thermophysical Properties Research Center. The work was administered under the direction of the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, with Mr. John H. Charlesworth (MAAM) acting as Air Force project engineer.

This report covers work conducted from 1 January 1969 to 31 December 1969. Dr. Y. S. Touloukian has been the principal investigator and program director. The report was submitted by the author in March 1970.

All the staff of TPRC's Administration, Data Tables Division, Scientific Documentation Division, Engineering Graphics Unit, and Technical Typing Unit have contributed to this program. In particular, the following members of TPRC's professional staff have contributed greatly to the respective projects: Dr. R. W. Powell (senior investigator), Mr. K. Y. Wu, and Mrs. E. K. C. Lee to the tables of thermal conductivity of solids; Dr. P. E. Liley (senior investigator) to the tables of thermal conductivity of fluids; Dr. T. Makita (senior investigator), Dr. Y. Tanaka, Mr. K. Ueda, Miss K. Inoue, and Miss E. Hata to the tables of specific heat of fluids; Dr. D. P. DeWitt (senior investigator), Mr. M. C. Muinzer, Mr. R. S. Hernicz, Dr. J. J. Hsia, Mrs. S. L. Miller, and Mr. K. F. Sohn to the tables of thermal radiative properties; Dr. M. C. Nicolaou (senior investigator) to the tables of thermal diffusivity; Dr. P. Hestermans (senior investigator) and Dr. S. C. Saxena (senior investigator) to the tables of viscosity; Dr. R. E. Taylor (senior investigator), Mr. P. L. Wang, Mr. B. M. Whitcomb, Mr. S. N. Vo, and Mr. M. Nalbantyan to the tables of thermal expansion; Mr. W. H. Shafer to the technical inquiry services; Prof. F. E. Davis to the computerized information storage and retrieval; Mrs. J. K. Gerritsen, Mrs. N. Y. Moore, Mrs. B. M. Schick, Mrs. C. A. Pelikan, Mrs. V. Ramdas, Mr. G. Kvakovszky, Mrs. S. A. O'Kane, Mrs. K. Singleton, and Mrs. M. R. Troyer to the extensive documentary work so necessary to make the tables projects possible.

This technical report has been reviewed and is approved.

EDWARD DUGGER, Chief
Materials Information Branch
Material Support Division
Air Force Materials Laboratory

ABSTRACT

This technical report covers work in a continuing systematic program on the thermophysical properties of materials involving the literature search, acquisition, codification, and organization, and data extraction, compilation, evaluation, correlation, analysis, and synthesis, the preparation of "intermediate tables" presenting the total available experimental information, and the final preparation of internally consistent tables of "best data" referred to as "Tables of Recommended Reference Values." The work reported on consists of both data tables projects and scientific documentation efforts. The data tables projects are on the thermal conductivity, specific heat, thermal radiative properties (emittance, reflectance, absorptance, transmittance), thermal diffusivity, and thermal linear and volumetric expansion of elements, ferrous and nonferrous alloys, intermetallic, semiconducting, and nonmetallic compounds, cermets, ceramics, mixtures, composites, systems, polymers, etc., and on the thermal conductivity, specific heat, and viscosity of fluids and fluid mixtures. Property data are presented in both tabular and graphical forms, with accompanying tables giving specifications and characterizations of the test specimens for the data. The resulting data tables are disseminated at large though the 13-volume TPRC DATA SERIES published commercially. This report does not contain the completed thousands of data sheets, but does reproduce in the Appendix, the Table of Contents and the Grouping of Materials and List of Figures and Tables for each of the first seven volumes (which contain over 8000 pages) of the TPRC DATA SERIES to show the scope of their coverage. In scientific documentation, the scope is broader. TPRC covers all materials and maintains cognizance over sixteen thermophysical properties (six more than mentioned above). There are now 55 700 references in TPRC's automated Information Storage and Retrieval System. The resulting information on research literature is disseminated through the THERMOPHYSICAL PROPERTIES RESEARCH LITERATURE RETRIEVAL GUIDE, published commercially.

TABLE OF CONTENTS

SECTION I

INTRODUCTION

The knowledge of the properties of materials is of great importance in modern science and engineering. The present obstacles and limitations in many technological developments are often a direct result of the paucity of knowledge of the properties of materials. The ever increasing amount of activities in property determinations in recent years attests to the seriousness of the situation with the result that the volume of research literature has increased many fold. Despite the widespread efforts, the present level of research on thermophysical properties of materials still falls short of existing needs and anticipated future demands. However, what is even more disturbing is the fact that engineers across the nation are using no more than a small fraction of the information already existent, either because its existence is not generally known to them or because it is in a form not directly usable, and such information remains buried in the world's technical literature.

The Thermophysical Properties Research Center (TPRC) has been pioneering to provide a remedy to this disturbing situation by conducting a continuing systematic program for more than a decade to dig the buried treasures out of the world's enormous volume of literature and put them in a form directly useful to engineers and scientists at large. This program on the thermophysical properties of materials involves the literature search, acquisition, codification, and organization, and data extraction, compilation, evaluation, correlation, analysis, and synthesis, the preparation of "intermediate tables" presenting the total available experimental information, and the final preparation of internally consistent tables of "best data" referred to as "Table of Recommended Reference Values."

The data tables projects of this program include the thermal conductivity, specific heat, thermal radiative properties (emittance, reflectance, absorptance, transmittance), thermal diffusivity, and thermal linear and volumetric expansion of elements, ferrous and nonferrous alloys, intermetallic, semiconducting, and nonmetallic compounds, cermets, ceramics, composites, mixtures, systems, polymers, etc., and the thermal conductivity, specific heat, and viscosity of fluids and fluid mixtures. Property data are presented in both tabular and graphical forms, with accompanying tables giving specifications and characterizations of the test specimens for the data. The resulting data tables are disseminated at large through the 13-volume TPRC DATA SERIES published commercially.

In scientific documentation, the scope is broader. TPRC covers all materials and maintains cognizance over the following sixteen thermophysical properties: thermal conductivity, accommodation coefficient, thermal contact resistance, thermal diffusivity, specific heat, viscosity, emittance, reflectance, absorptance, transmittance, absorptance to emittance ratio, Prandt number, diffusion coefficient, thermal linear expansion coefficient, thermal volumetric expansion coefficient, and surface tension. The resulting information on research literature is disseminated through the THERMOPHYSICAL PROPERTIES RESEARCH LITERATURE RETRIEVAL GUIDE, published commercially.

The overall activities of TPRC are divided into four areas: namely, (1) Scientific Documentation, (2) Generation of Data Tables, (3) Experimental Research, and (4) Theoretical Research. The activities discussed in this report cover the first two areas.

The literature search, information processing, and data processing for preparing the Retrieval Guide and the TPRC Data Series and the status of the various active projects are outlined in the following sections. It should be noted that part of the projects discussed below are not funded under this contract.

SECTION II

SCIENTIFIC DOCUMENTATION

1. LITERATURE SEARCH AND INFORMATION PROCESSING

The Scientific Documentation Division of TPRC provides comprehensive and authoritative source information on the thermophysical properties of all matter through continuing and systematic literature search, acquisition, codification, and organization of the existing information in the world literature, and putting the information in TPRC's automated Information Storage and Retrieval System.

From 1957 to 1964 TPRC has searched the world literature primarily through sixteen abstracting journals. This search, covering the publication period from January 1920 to June 1964, has involved the scanning of approximately 33 400 000 abstracts out of approximately 81 000 000 abstracts reported by these journals. Out of the 33 400 000 abstracts scanned, only 52 500 (0.16%) were considered pertinent. Subsequent examination and checking of the 52 500 abstracts and the original papers revealed a large number of duplications between the various abstracting journals and nearly 9900 irrelevant ones, leaving a net total of 28 800

research documents obtained from these sources. In addition to abstracts, 4900 documents had come to TPRC's attention from other sources making a total of 33 700 documents up to June 1964. These 33 700 references are covered in the revised second edition of the Retrieval Guide published in October 1967.

Subsequently, in preparation for future Retrieval Guide publications, an additional 22 000 reference entries have been made. Thus, as of 31 December 1969 there are 55 700 references identified for TPRC's Information Storage and Retrieval System. The above figures give an insight as to the magnitude of the effort involved in a thorough search of world knowledge even in a relatively specialized field. The overall current statistical data for TPRC's scientific documentation are presented in Table I.

When the retrospective search of the world literature, primarily through the medium of abstracting journals, was completed early in 1965, TPRC reviewed its procedure of using abstracting journals for the identification of current literature on thermophysical properties research. It was recognized that continued use of abstracting journals for research awareness would represent, at best, one to two years delay in identifying and procuring such literature, with the result that bibliographic searches provided by TPRC could not be on a reasonably current basis. Hence, beginning in 1965 TPRC has subscribed to some 80 highly selected scientific and technical journals to obtain current research articles. To complete the literature search, the Chemical Abstracts continue to be scanned to cover the open literature and several government abstracting journals such as the Scientific and Technical Aerospace Reports, U. S. Government Research and Development Reports, etc. are scanned to cover the government report literature. In addition to these basic sources, TPRC searches certain specialized sources such as Masters Theses in the Pure and Applied Sciences, Doctoral Dissertation Abstracts, and a number of special compendia. Of particular note here are the two overseas Branches of TPRC at Brussels, Belgium, and Kobe, Japan, who serve a very important input function for European and Far Eastern literature*. Furthermore, TPRC continues to develop its cooperative working arrangements on the exchange of research results and scientific information with major national and international institutions engaged in thermophysical properties research. As a result of this policy, TPRC is now able to keep abreast of current research with an average time

*These TPRC overseas Branches are not supported under this contract.

TABLE I. STATISTICAL SUMMARY OF SCIENTIFIC DOCUMENTATION ACCOMPLISHMENTS

(As of 31 December 1969)

	In 1969	Total at End
Documents identified	4 261	55 700
Documents received	10 747	56 628
Documents coded	6 605	47 651
Reference entries on all properties	16 804	183 135

Reference Entries by Property
(Since publication of Retrieval Guide, 2nd edition)

	Reference Entries (In 1969)	Reference Entries (Total at End)	% of File (At End)
Thermal conductivity	3 371	8 989	20.51
Specific heat	2 389	6 299	14.37
Diffusion coefficient	1 385	4 905	11.19
Viscosity	1 848	4 731	10.79
Thermal linear expansion coefficient	2 526	4 202	9.59
Reflectance	1 307	3 511	8.01
Surface tension	1 252	3 205	7.31
Transmittance	875	3 067	7.00
Emittance	481	1 470	3.35
Absorptance	347	1 133	2.59
Thermal diffusivity	302	841	1.92
Thermal volumetric expansion coefficient	200	593	1.35
Accommodation coefficient	241	374	0.85
Thermal contact resistance	192	282	0.64
Prandtl number	73	146	0.33
Absorptance to emittance ratio	15	82	0.19
Total	16 804	43 830*	100%

*There are 139 305 reference entries (see Table II) in Book 2 of Retrieval Guide, 2nd Edition, making a grand total of 183 135 reference entries as of 31 December 1969.

lag from document publication to acquisition not to exceed six months. Besides being used as input to the Data Tables Projects at TPRC, the information acquired under the documentary phase of this program is intended to render technical inquiry services to governmental, industrial, and academic laboratories in answering questions on thermophysical properties.

A statistical study completed in late 1968 showed that some 330 of the total over 3600 scientific and technical journals cited to date yielded more than 85 percent of the articles. The top-yielding 50 journals subscribed by TPRC plus all the government reports, Ph.D. dissertations, and masters theses received by TPRC yielded over 60 percent of the current holdings.

It would be desirable to replace the manual literature searching and scanning by computer searching and scanning if it could be workable so as to reduce the time lag in document identification. However, it was found that, due to the prevailing inaccurate assignment of key words to articles, the computer could pick out less than 50 percent of the pertinent articles from the literature and the other 50 percent or more would be lost. Furthermore, the majority of the articles picked out by the computer would still have to be screened manually for being valid and useful for the documentation file. In view of the above, it appears that manual processing must continue for document identification and screening.

The problem of procuring research documents from the open literature is beginning to assume major proportions especially in the case of foreign literature and special publications of limited distribution. Therefore, TPRC's specialized holdings constitute a unique national asset and are assuming increasing importance for rapid access to the world literature on thermophysics and thermophysical properties. It is TPRC's experience that literature retrieval programs which yield only bibliographies as their end product are becoming increasingly less useful because of the time lapse involved in procuring the cited documents. To remedy this situation, TPRC has supplemented its long-standing practice of submitting bibliographic responses to literature search requests with copies of the actual documents in the form of standard microfiche. The conversion of TPRC's hard copy document holdings into microfiche form was completed during 1967.

2. RETRIEVAL GUIDE

The comprehensive second edition of the THERMOPHYSICAL PROPERTIES RESEARCH LITERATURE RETRIEVAL GUIDE was published in October 1967 by the Plenum Press.

This three-book volume represents the printout of a special computer program and provides quick access to the world literature on thirteen thermophysical properties of all matter. This definitive work contains a complete coverage of the world literature published from January 1920 (in some cases earlier) to June 1964 on thirteen thermophysical properties. Its 2800 pages (in 3 books) report 45 116 materials, citing 33 700 references representing 26 562 authors and 3600 separate scientific and technical journals and books in addition to Government reports. Its substance and property coverages are listed in Table II. The contents of the three books of the Retrieval Guide are as follows:

Book 1: Primarily constitutes TPRC's classified Directory of Substances in which information on the thirteen thermophysical properties are reported. Book 1 also contains three other major chapters which greatly enhance its usefulness. These consist of: (1) Guide to TPRC's Substance Classification Procedure and Numerical Codes; (2) Dictionary of Synonyms and Trade Names with a Listing of Cross References; and (3) Index to Mixtures.

Book 2: Contains the classified code entries and publication year of each reference for each property of each material. The classified code entries cover the following:

Phys. State:	1-Solid; 2-Liquid; 3-Gas; 4-Semi-solid; 5-Powder; 6-Suspensoid; 7-Sintered; 8-Solid-Gas system; 9-Solid-Liquid system.
Subject:	1-Theoretical; 2-Experimental; 3-Theo. and Exp.; 4-Property values; 5-Theo. and Prop. val.; 6-Exp. and Prop. val.; 7-Theo., Exp., and Prop. val.; 8-Survey, Review, Compendia, or Bibliography.
Language:	1-Eng.; 2-Fr.; 3-Ger.; 4-Dutch; 5-It.; 6-Jap.; 7-Rus.; 8-Span.; 9-Other.
Temperature:	1-Low, 0 to 75 K; 2-Normal, 75 to 1275 K; 3-High, 1275 K and up; 4-(Low + Normal); 5-(Normal + High); 6-(Low + Normal + High); 7-Not specific.

Book 3: Part A provides bibliographic citations for the 33 700 references covering scientific and technical journals in addition to university dissertations and

TABLE II. SUBSTANCE AND PROPERTY COVERAGES OF RETRIEVAL GUIDE*

SUBSTANCE COVERAGE - All Matter	
Elements and chemical compounds	9 030
Ferrous and nonferrous alloys	9 970
Mixtures	13 396
Systems, composites, etc.	1 643
Polymers, rubbers, etc.	2 600
Refractories	961
Glasses	1 109
Natural products	1 100
Minerals	662
Paints, surface finishes, coatings	2 632
Slags, scales, aggregates, cermets, fuels, lubricants, fibers, fabrics, pharmaceuticals, insulations, building materials, residues, etc.	1 967
General	46
Total number of substances	45 116

PROPERTY COVERAGE - Transport and Thermodynamic Properties Encountered in Heat and Mass Transfer Calculations	
Thermal conductivity (including accommodation coefficient and thermal contact resistance)	31 050
Specific heat	28 030
Viscosity (Newtonian and non-Newtonian; including fluidity)	46 870
Thermal radiative properties (emittance, reflectance, absorptance, transmittance, and optical constants)	9 400
Diffusion coefficient	21 720
Thermal diffusivity	1 705
Prandtl number	540
Total number of reference entries	139 305

*This storehouse of information has come from 33 700 references representing 26 562 authors and 3600 separate scientific and technical journals and books in addition to sources of governmental and industrial reports (e.g., Defense Documentation Center, Clearinghouse for Federal Scientific and Technical Information, Atomic Energy Commission, National Aeronautics and Space Administration, research centers, and the like).

technical reports of governmental agencies, industrial organizations, and research centers and laboratories. Part B contains an index to names of contributing authors.

Effective January 1967, the scope of property coverage by TPRC was increased to include the coefficients of linear and volumetric thermal expansion and surface tension. Furthermore, each thermophysical property is coded separately instead of the past practice of coding several related properties in groups. For instance, the thermal conductivity, accommodation coefficient, and thermal contact resistance were formerly all coded under the property thermal conductivity. They are now coded separately as individual properties. Similarly, the five entries under thermal radiative properties are now listed separately as individual properties. Thus, effective since January 1967, TPRC maintains cognizance over sixteen thermophysical properties for all materials. They are:

A. Thermal conductivity
B. Accommodation coefficient
C. Thermal contact resistance
D. Thermal diffusivity
E. Specific heat at constant pressure
F. Viscosity
G. Emittance
H. Reflectance
I. Absorptance
J. Transmittance
K. Absorptance to emittance ratio
L. Prandtl number
M. Diffusion coefficient
N. Thermal linear expansion coefficient
O. Thermal volumetric expansion coefficient
P. Surface tension

The code entries are also revised as follows:

Physical State: A-Solid (including porous); B-Liquid; C-Gas; D-Powder (loose or cold-pressed - including coarser granular particles), for example, sand; E-Sintered (including hot-pressed); F-Suspensoid (including fine emulsions), for example, petroaltum, blood, milk, paint, mud, clay, paste, gel, etc.; G-Powder - fluid system (including coarser granular particles), for example, sand + liquid, fluidized bed, glass spheres suspended in glycerin, etc.; H-Solid - fluid system, for example, contact in gaseous atmosphere, etc.; I-Liquid - gas system.

Subject: A-Theoretical (about properties) - Original theory or a sufficient amount of modification of existing theory. A theoretical discussion. Analytical development for the prediction of results; B-Experimental - Description, discussion or theory about experimental technique or apparatus for the determination of property values; C-Property Values - Calculated or measured data with no theory or experimental techniques discussed. Limited

data compendia, correlations and nomographs are included here; D-Theoretical and Experimental - Combination of codes A and B; E-Theoretical and Property Values - Combination of codes A and C; F-Experimental and Property Values - Combination of codes B and C; G-Theoretical, Experimental and Property Values - Combination of codes A, B and C; H-Survey or Review - Critical or informative survey or review on a broad scale about experimental techniques or theories; I-Data Collections - Compilation of data on a broad scale (critical or uncritical). Handbooks, data books, encyclopedias, etc.

Language: A-Eng.; B-Fr.; C-Ger.; D-Dutch; E-It.; F-Jap.; G-Rus.; H-Span.; I-Other.

Temperature: A-Low ≤-198 C, ≤135 R, ≤-325 F, ≤ 75 K; B-Normal, ≤1000 C, ≤2292 R, ≤1832 F, ≤1273 K; C-High, >1000 C, >2292 R, >1832 F, >1273 K; D-Low + Normal; E-Normal + High; F-Low + Normal + High; G-Undefined.

3. AUTOMATION AND COMPUTERIZED INFORMATION STORAGE AND RETRIEVAL SYSTEM

With the installation of the new CDC 6500 computer facility at Purdue University in summar 1967, TPRC's long needed capability of full mechanization in its search and retrieval operations has been fulfilled. As a result, TPRC now has an automated bibliographic search capability to respond to specific inquiries or to process standing requests for a continuing bibliographic service tailored to meet demands for specific technical profiles of individual engineers, scientists, corporations, laboratories, or governmental agencies.

During 1969, TPRC will continue to generate, quarterly, miniature "Retrieval Guide" for each property in order to serve its own inhouse programs as well as subscribers at nominal costs. For the future, it is considered to generate a series of Retrieval Guides for individual properties for formal publication so as to parallel the property-oriented 13-volume TPRC Data Series.

SECTION III

DATA TABLES PROJECTS

1. DATA PROCESSING PROCEDURES

As a result of the comprehensive search of literature in the scientific documentation phase of this program described above, the original research papers of interest to TPRC are uncovered. These papers are procured, from which the data are extracted, scrutinized, organized, converted to be in uniform units, and homogeneously tabulated and plotted, in the form of "intermediate tables" presenting the total available experimental information, as the first stage toward the preparation of internally consistent tables of "best data" referred to as "Tables of Recommended Reference Values." TPRC senior staff then review this information and give the organized data final critical evaluation. At this second stage, the experimental data are analyzed, correlated, and synthesized. This two-stage data processing is found by TPRC to be the most logical approach lending itself to greater effectiveness in bringing to the user the results of this type of painstaking research in the shortest possible time.

The detailed procedures which TPRC follows in data compilation and in data analysis and synthesis are not necessarily a matter of established routines and do vary from property to property and from one group of materials to another. There are certain principles which must be followed, however. For example, the data should be extracted directly from their original sources to ensure freedom from errors of transcription. The characterization of the test specimen should be specified as clearly as possible so as to fully identify the material tested. Especially for solids, the source of the material, method of fabrication, treatment and heat history of the specimen and the measuring method and conditions should be noted. If a comparative measuring method is used, the material used as comparative standard should be cited. The accuracy and precision of the data reported should be separately denoted. The complete reference to the original work should always be cited with the data. Whenever some of the above criteria cannot be satisfied because of absence of necessary information in the original work, an attempt is made to contact the author, if possible. In the cases where data cannot be adequately evaluated by TPRC due to lack of required information, such data are appropriately "flagged."

TPRC's Gerber Data Point Reader has been in full operation to accurately and speedily read data points off graphs presented in the research literature. Whenever the graph is too small to give accurate readings, an attempt is made to contact the author, if possible, for original data in tabular form.

In connection with its activities in data processing, TPRC has established, through experience, appropriate procedures of operational practice which lend to good organization of work, uniform recording and filing, and other procedures of "good housekeeping," thus assuring ready tractability of original records of processed data as permanent working records for reference at any time in the future.

The procedure in data analysis and synthesis involves critical evaluation of the validity of available data and related information, resolution and reconciliation of disagreements of conflicting data, correlation of data in terms of various affecting parameters (sometimes in reduced form), comparison of the resulting data with theoretical predictions or with results derived from semi-theoretical relationships or from generalized empirical correlations, etc. Furthermore, thermodynamic principles and semi-empirical techniques are employed to fill in gaps and to extrapolate existing data so that the resulting recommended values are internally consistent and cover as wide a range of the controlling parameters as possible.

2. ACTIVE PROJECTS

TPRC data tables projects include the thermal conductivity, specific heat, thermal radiative properties (emittance, reflectance, absorptance, transmittance), thermal diffusivity, and thermal linear and volumetric expansion of elements, ferrous and nonferrous alloys, intermetallic, semiconducting, and nonmetallic compounds, cermets, ceramics, composites, mixtures, systems, polymers, etc., and the thermal conductivity, specific heat, and viscosity of fluids and fluid mixtures. Table III gives a statistical summary of the accomplishments in 1969 of all the data tables projects. Part of the projects are, however, not funded under this contract.

The resulting data tables are to be disseminated at large through the 13-volume TPRC DATA SERIES, as described in more detail later in the next subsection. A summary of the statistical data on the completed Volumes 1 to 7 of the TPRC DATA SERIES is given in Table IV. The property data are presented in both tabular and graphical forms, with accompanying tables giving specifications and characterizations of the test specimens for the data.

TABLE III. STATISTICAL SUMMARY OF ACCOMPLISHMENTS OF ACTIVE DATA TABLES PROJECTS

(As of 31 December 1969)

	In 1969	Total at End
No. of documents processed	6892	16 094
No. of documents accepted as data sources	2259	7 311
No. of materials compiled	1073	5 437
No. of data sets compiled	9642	38 270

TABLE IV. SUMMARY OF STATISTICAL DATA ON VOLUMES 1 TO 7 OF "TPRC DATA SERIES"

	No. of Pages	No. of Materials	No. of Data Sets	No. of References to Data Sources*
Volume 1. Thermal Conductivity - Metallic Elements and Alloys	1600	892	5539	1013
Volume 2. Thermal Conductivity - Nonmetallic Solids	1300	812	4627	598
Volume 3. Thermal Conductivity - Nonmetallic Liquids and Gases	700	170	1505	725
Volume 4. Specific Heat - Metallic Elements and Alloys	820	322	1186	428
Volume 5. Specific Heat - Nonmetallic Solids	1730	550	1009	457
Volume 6. Specific Heat - Nonmetallic Liquids and Gases	380	56	863	595
Volume 7. Thermal Radiative Properties - Metallic Elements and Alloys	1650	242	5184	371

*These are the references to data sources only, not including those references to the text on the theory, estimation, and measurement of the respective thermophysical properties.

The following brief summaries will serve to characterize each of the data tables projects.

a. Thermal Conductivity

Thermal conductivity constitutes Volumes 1, 2 and 3 of the TPRC DATA SERIES. The data compilation and critical evaluation and the generation of recommended reference values for the thermal conductivity of the elements is totally completed and is being maintained on a current basis. For the other groups of materials the work is finished to various degrees depending upon the importance of the various groups of materials. It has been a standing practice to try to finish the data processing for the most current research documents first and then to work backwards on the older documents of earlier years. Because of the immense amount of new research documents generated every year and because of the limited funding level and man-year effort, it is impossible at the present level of operation to process completely all the research documents for all the materials.

In the Retrieval Guide, second edition, which contains 33 700 references, there are 7329 references on thermal conductivity, i.e., 21.7 percent (neglecting the relatively small number of references on accommodation coefficient and thermal contact resistance). The present rate of document input into TPRC's Information Storage and Retrieval System is about 6000 per year. If the past ratio remains approximately the same, as indicated by the relative file size (20.51%) for thermal conductivity shown in Table I, there are over 1200 new documents per year on thermal conductivity entering TPRC System. Therefore, it becomes a too arduous task even just to maintain current by processing the most recent documents, 1200 per year. A similar situation is present for most of the other projects.

The thermal conductivity of metals, alloys, and intermetallic compounds, which are organized into seven groups, is included in Volume 1 of the TPRC DATA SERIES. Besides the presentation of experimental data, recommended values are given for the elements and for a few alloys. Volume 2 presents data for thirty groups of nonmetallic solids. Recommended values are given for the elements and a few oxides. Volume 3 contains the critically evaluated and recommended reference values for 58 fluids and also the compiled data for 112 systems of gas mixtures which are organized into four groups. The pure fluids are organized into three groups; for the elements recommended values are given for solid, saturated liquid, saturated vapor, and gaseous states while for the other two groups of pure fluids, recommended values are given for saturated liquid and gaseous states. See the Appendix for complete lists of the materials covered.

Since all the three volumes on the thermal conductivity are completed, in addition to updating and upgrading the existing tables and compiling data for new materials, the future efforts will also include the critical analysis of the data for alloys of Volume 1 and refractory oxides of Volume 2 and the extension of the work on Volume 3 to the thermal conductivity of an increasing number of refrigerants and to the high-pressure effect on the thermal conductivity of liquids and gases.

b. Specific Heat

Specific heat constitutes Volumes 4, 5 and 6 of the TPRC DATA SERIES. Tables on the specific heat of the elements and of all the important alloys, intermetallics, compounds, cermets, and mixtures have been prepared. Data on the specific heat of metallic elements and alloys and nonmetallic solids are compiled here at TPRC while the work on nonmetallic liquids and gases is done at TPRC's Kobe Affiliate in Japan.

The specific heat of the metals and alloys, which are organized into four groups, is included in Volume 4. Volume 5 presents data for twenty-four groups of nonmetallic solids. Volume 6 contains the critically evaluated and recommended reference values for 56 fluids organized into four groups, and the recommended values are given for both liquid and gaseous states.

Besides updating and upgrading the existing tables and compiling data for new materials, the future efforts will also include the critical analysis of the data for the elements of Volumes 4 and 5 and the extension of the work on Volume 6 to the specific heat of an increasing number of refrigerants and to the high-pressure effect on the specific heat of liquids and gases.

c. Thermal Radiative Properties (Emittance, Reflectance, Absorptance, and Transmittance)

This group of properties constitutes Volumes 7, 8 and 9 of the TPRC DATA SERIES. The radiative properties of metals and alloys are presented in the completed Volume 7. Volume 8 will contain the data for many groups of nonmetallic solids, while Volume 9 will present the data for coatings of all types, especially those particularly suitable for thermal control and for high temperature applications.

The present tables are organized in a way that is much different from that in the original TPRC Data Book. It is due to the establishment of a better scheme for the designation and categorization of the subproperties. According to the new scheme, by applying the proper geometric conditions (angular, normal, hemispherical) and

wavelength conditions (spectral, total, integrated, solar) to the four prime properties, there are althogether thirty-three subproperties for any one material. The wavelength range covers from 500 Å to 1000 μm, which encompasses the thermal portion of the spectrum, and special attention is given to solar spectrum conditions.

In addition to the presentation of original data, the data for many materials have been analyzed and "analyzed data graphs" are presented in parallel to give the user an evaluated review of the available data and where possible to recommend values under specific environmental conditions.

Since Volume 7 is now completed, the major efforts are concentrated on the processing of data on nonmetallic solids and coatings. A new classification scheme for coatings has been developed after considerable study by the TPRC staff in consultation with several national experts. The coatings are now classified into conversion-diffusion coatings, contact coatings, pigmented coatings (vitreous enamels and paints), and uncharacterized coatings (commercial designations).

Although in the Retrieval Guide, second edition, there are only 2829 references on thermal radiative properties (8.4 percent of the 33 700 references), in recent years the number of new research documents on the thermal radiative properties has increased steadily and rapidly. Presently, 21 percent of the TPRC annual input are related to thermal radiative properties, and a half of these documents contains information on coatings.

d. Thermal Diffusivity

Thermal diffusivity will constitute Volume 10 of the TPRC DATA SERIES. The work on this property has been greatly accelerated since 1968. All the previous tables have been completely updated and revised and new research documents are processed to extend the scope of coverage. The recommended values for the thermal diffusivity of the elements are being generated also. Volume 10 of the TPRC DATA SERIES will be published in late 1970 and will contain the thermal diffusivity of elements, alloys, and many groups of nonmetallic solids.

e. Viscosity

Viscosity will constitute Volume 11 of the TPRC DATA SERIES. The work on this property had been suspended from 1964 to 1966. Starting early 1967 this work was reactivated in TPRC's European Branch at the Belgian Institute for High Pressure, Brussels, Belgium.

Data compilation for the same 56 fluids as covered by Volume 6 of the TPRC DATA SERIES and also for a number of refrigerants is well under way. Critical evaluation of the compiled data so as to generate the recommended reference values is also in progress. A computational procedure for generating the recommended values from experimental data has been fully established. This Volume 11 will be published in 1971.

f. Thermal Expansion (Linear and Volumetric)

Thermal expansion will constitute Volumes 12 and 13 of the TPRC DATA SERIES. This project was initiated in mid-1968 and has since been in full progress. The work includes both linear and volumetric expansion and covers elements, alloys, intermetallic compounds, and various groups of nonmetallic solids. The two volumes are planned to be published in 1972.

3. TPRC DATA SERIES

Synthesis of existing fragments of knowledge is as important as so-called original observation. The availability of adequate standard reference data tables is essential to national progress, economy, and defense. To this end TPRC has contributed greatly through the generation and dissemination of data tables on thermophysical properties.

The 13-volume TPRC Data Series brings together the most comprehensive and authoritative compilations of existing numerical data on thermophysical properties of materials. Recommended reference values of particular properties for particular materials are also often included. This new TPRC Data Series has evolved from the old three-volume loose-leaf 11" x 17" size TPRC Data Book, which was disseminated by TPRC from 1960 to 1967 and is well known nationally and, indeed, internationally. As of January 1967, the old TPRC Data Book contains 3322 data sheets, reporting 11 425 test specimens and citing 3424 references.

In view of the old TPRC Data Book's continuing rapid growth since 1960 and the extensive physical proportions it had assumed and in order to eliminate the cumbersome merging of supplements and the associated high cost of dissemination, it was decided in 1967 to discontinue the procedure of publication in loose-leaf format and its semi-annual dissemination by TPRC. Instead, the old Data Book has been restructured into volumes by properties and extensively updated, upgraded, and enlarged to become this new TPRC Data Series in 13 volumes.

One of the major improvements of the new TPRC Data Series over the old Data Book is that each volume of the Data Series includes also a comprehensive text on the theory, estimation, and measurement of the property and an overall material index, in addition to the most comprehensive compilation of numerical data. The text provides a general background and review of the theory and physics of the property considered in that volume, the methods for estimating the property values when experimental data are not available, and the experimental methods and apparatus for measuring the property. Such a background information enables the user to properly and fully utilize the compiled data and also enhance the usefulness of the data themselves. The material index lists alphabetically all the materials contained in that volume and in the companion volumes on the same property together with their respective volume numbers and page numbers. Many commercial designations of materials are cross-indexed with their previous designations and synonyms are cross-indexed with each other. Thus it enables the user to quickly locate the data for any material contained in the volume or in the companion volumes and to completely retrieve the desired data.

The numerical data for each material (except for the pure fluids) are presented in a full-page figure and also tabulated in a data table, accompanied by a specification table providing for every set of data a concise description of the sample characterization, as well as the method of measurement and test conditions. For the pure fluids of Volumes 3, 6 and 11, a critical discussion is given for each fluid in place of the specification table for the samples and data table for the raw data, which are presented through a departure plot, since all data have been critically reviewed and recommended values are presented.

Table V gives an indication of the structure, scope, and publication schedule of the TPRC Data Series. The first seven volumes of the Data Series have been completed and are in the publisher's hands for printing. They will soon be available through Plenum Press, New York, in the form of formal hard-bound volumes, 9-1/4" x 11-1/4" in size. It is contemplated that work on Volumes 8, 9 and 10 will be completed in late 1970. Table V also reflects the substantial increase in scope of Volumes 12 and 13, which are now anticipated to comprise 1000 pages each instead of 500 pages projected a year ago. The Table of Contents and Grouping of Materials and List of Figures and Tables of the completed first seven volumes are given in the Appendix.

TABLE V. PUBLICATION SCHEDULE FOR TPRC DATA SERIES*

	1970	1971	1972	1973	1974	1975	1976	1977	1978
Volume 1. Thermal Conductivity - Metallic Elements and Alloys	First Ed. 1600				Second Edition				
Volume 2. Thermal Conductivity - Nonmetallic Solids	First Ed. 1300				Second Edition				
Volume 3. Thermal Conductivity - Nonmetallic Liquids and Gases	First Ed. 700				Second Edition				
Volume 4. Specific Heat - Metallic Elements and Alloys	First Ed. 820					Second Edition			
Volume 5. Specific Heat - Nonmetallic Solids	First Ed. 1730					Second Edition			
Volume 6. Specific Heat - Nonmetallic Liquids and Gases	First Ed. 380					Second Edition			
Volume 7. Thermal Radiative Properties - Metallic Elements and Alloys	First Ed. 1650						Second Edition		
Volume 8. Thermal Radiative Properties - Nonmetallic Solids	First Ed. 880						Second Edition		
Volume 9. Thermal Radiative Properties - Coatings	First Ed. 1690						Second Edition		
Volume 10. Thermal Diffusivity	First Ed. 500							Second Edition	
Volume 11. Viscosity		First Ed. 600						Second Edition	
Volume 12. Thermal Expansion - Metallic Elements and Alloys			First Ed. 1000						Second Edition
Volume 13. Thermal Expansion - Nonmetallic Solids			First Ed. 1000						Second Edition

*Figures given under First Ed. represent estimated numbers of pages for the volumes. After the second edition, subsequent editions of each volume are to be released at intervals of five years.

As more volumes are readied for publication, an increasing number of the data tables and a number of the complete volumes will be in the form of critically evaluated and analyzed reference data. In fact, in the years ahead an increasingly larger portion of TPRC's total effort will be directed toward data analysis and synthesis along with data compilation. The former is a slow and painstaking task seldom fully appreciated by those who have not been involved with the generation or use of such information.

The continuing and systematic nature of this program makes the TPRC Data Series unique, quite distinctive from other data sources or handbooks, in that its coverage is constantly updated to maintain current and constantly upgraded to include more and more critically evaluated and analyzed standard reference data. Furthermore, for those users who have need for the most up-to-date information, TPRC will provide specific inquiry services or one may subscribe to the automatic data update plan tailored to meet a specific technical profile of an engineer, scientist, corporation, or laboratory. Thus, the user can always get the "last word" from the Data Series generator, TPRC.

The above-outlined procedure for data dissemination closely parallels the concept which TPRC has followed during the past twelve years for the dissemination of bibliographic information. In other words, TPRC publishes its major accomplishments in formal volumes through commercial channels while it directly disseminates up-to-date information to maintain its publications and audience on a current basis.

SECTION IV

TECHNICAL INQUIRY SERVICES

TPRC's contributions in information services continue to be primarily in the nature of technical advisory and consulting, data recommendations and predictions, and special bibliographic and data searches. During 1969, 436 inquiries (nearly nine per week) have been responded by TPRC covering various categories. Gratis responses to inquiries were given on an increasingly selective basis due to limited funds and time available for this purpose. Figure 1 gives an indication of the growth and distribution of these queries over the years. Figure 2 shows the detailed geographical distribution of the inquiries responded in 1969. As shown in Figure 2, these inquiries are from 36 states and District of Columbia and 21 foreign countries.

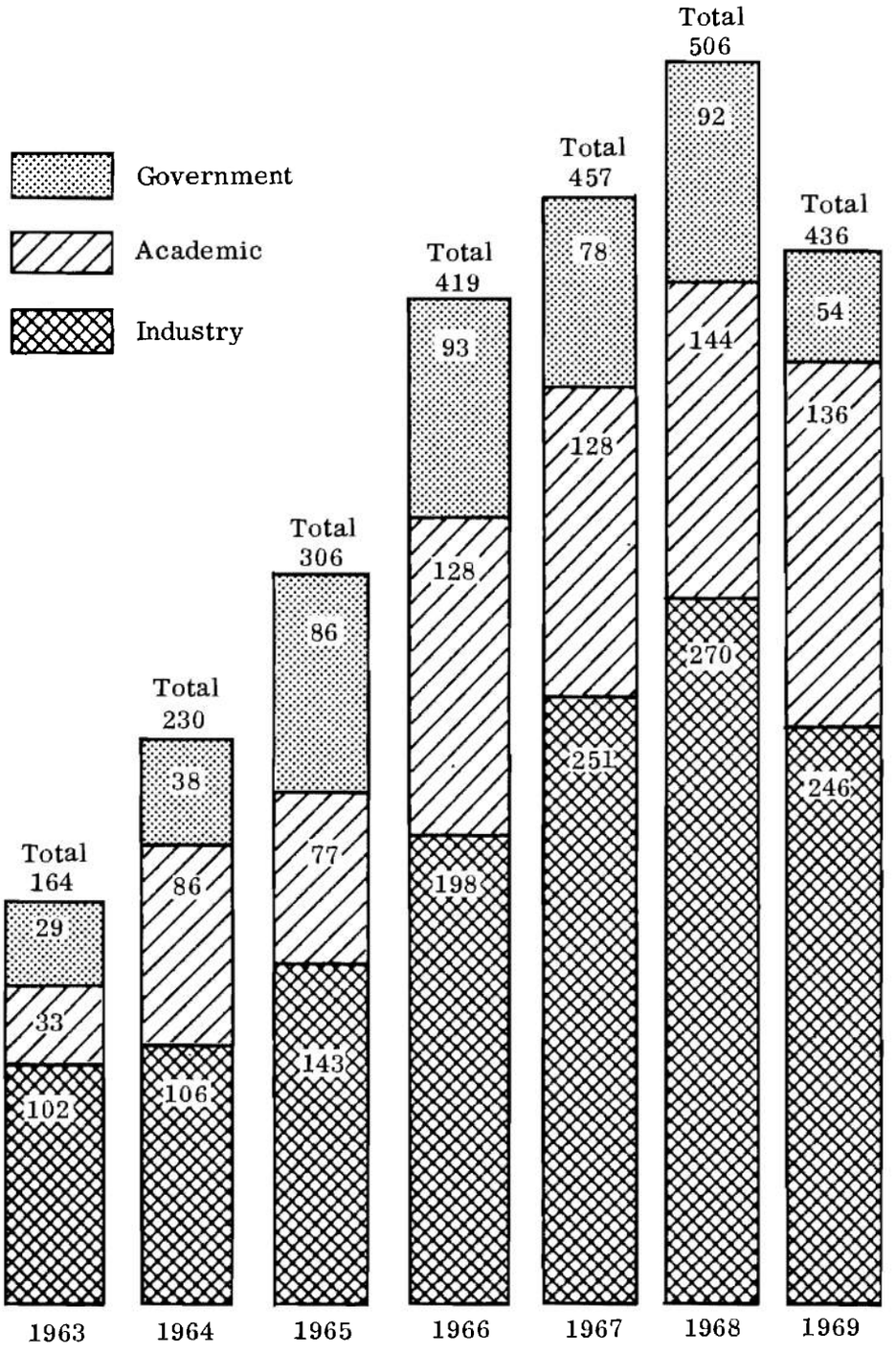

Figure 1. Growth and Distribution of TPRC's Inquiry Responses over the Years

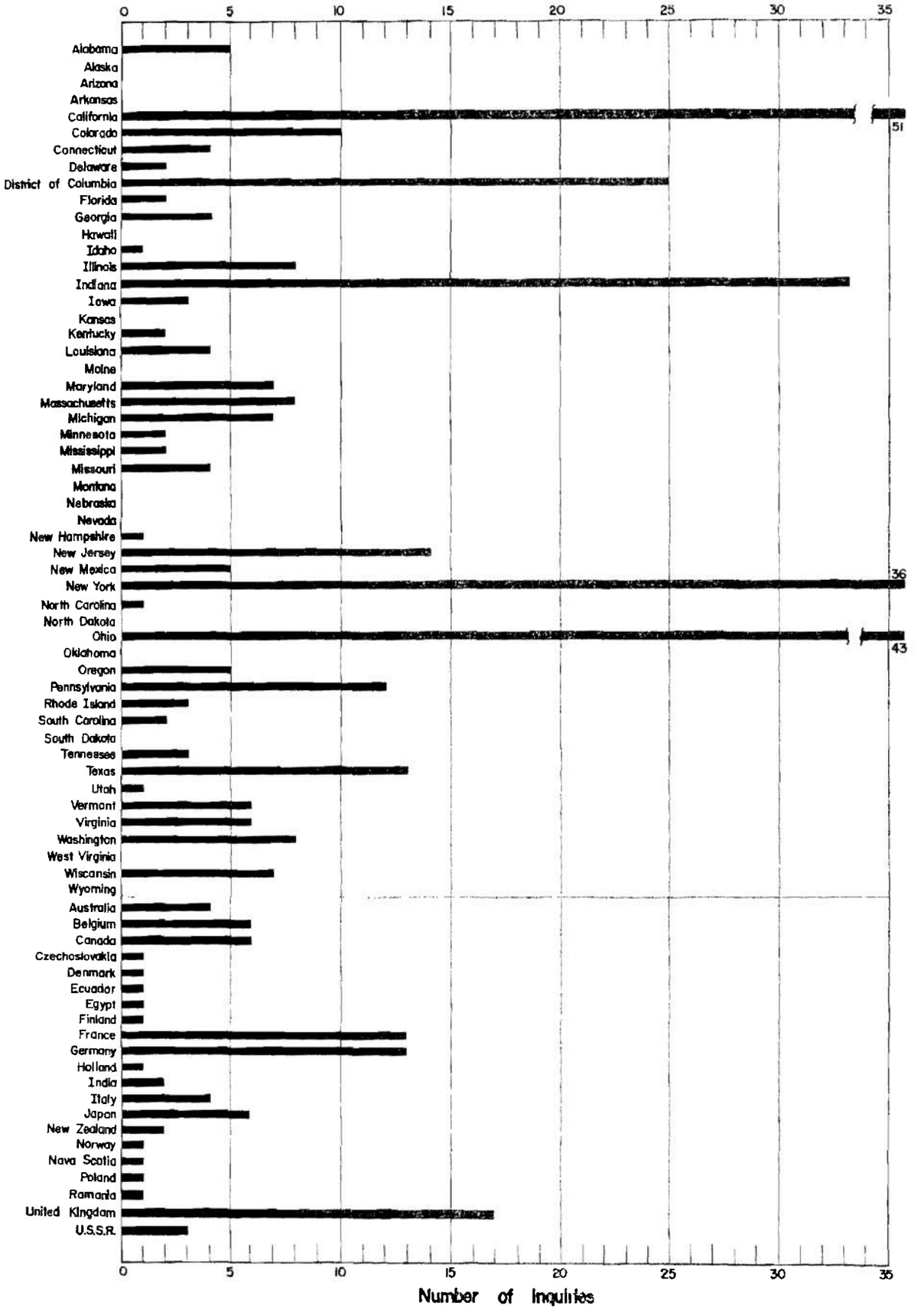

Figure 2. Geographical Distribution of Technical Inquiries for 1969

While Figure 1 indicates nearly a 14 percent decrease in the number of queries responded in 1969 over the preceding year, the time spent in answering these queries was 55 percent greater. It is of interest to note that, on the average, TPRC devoted approximately 72 hours to respond to a question requiring data analysis, 4.2 hours to answer a technical question, and 1.3 hours to respond to a query requesting literature. The average time spent per inquiry was 3.1 hours. These figures are substantially larger than the corresponding figures for 1968, primarily because TPRC devoted large block of time in 1969 to a few data analysis inquiries from the Air Force and NASA.

It is TPRC's aim and expectation that as our data books and other outputs are disseminated to the scientific and technical community on a worldwide basis through commercial publishers, the number of general technical inquiries will drop further. On the other hand, a larger number of engineers and scientists are becoming increasingly aware of TPRC's activities, thus reflecting a continuing increase in inquiries concerning TPRC's services and capabilities.

SECTION V

OTHER PUBLICATIONS AND RELATED WORK NOT UNDER THIS CONTRACT

1. THERMOPHYSICAL PROPERTIES OF HIGH TEMPERATURE SOLID MATERIALS

"Thermophysical Properties of High Temperature Solid Materials," Y. S. Touloukian (Editor), Vol. 1 to 6, MacMillan Company, New York, 8479 pp., 1967.

This major encyclopedic reference work consists of 6 volumes comprising 9 books (since Volumes 2, 4 and 6 consist of 2 books each) with a total of 8479 pages reporting data from 2447 references for 14 381 specimens in 1375 material groups. This work is available from the MacMillan Company as individual volumes as well as a complete set. The general contents of the respective volumes are as follows:

Volume 1 - Elements

Volume 2 - Nonferrous Alloys
- Part I - Nonferrous Binary Alloys
- Part II - Nonferrous Multiple Alloys

Volume 3 - Ferrous Alloys

Volume 4 - Oxides and Their Solutions and Mixtures
Part I - Simple Oxygen Compounds and Their Mixtures
Part II - Solutions and Their Mixtures of Simple Oxygen Compounds, Including Glasses and Ceramic Materials

Volume 5 - Nonoxides and Their Solutions and Mixtures, Including Miscellaneous Ceramic Materials

Volume 6 - Intermetallics, Cermets, Polymers, and Composite Systems
Part I - Intermetallics
Part II - Cermets, Polymers, and Composite Systems

The twelve specific properties covered in each volume are: density, melting point, heat of fusion, heat of vaporization, heat of sublimations, electrical resistivity, specific heat at constant pressure, thermal conductivity, thermal diffusivity, thermal linear expansion, thermal radiative properties (absorptance, emittance, reflectance, and transmittance), and vapor pressure.

2. NATIONAL STANDARD REFERENCE DATA SERIES

As a component of the National Standard Reference Data System - National Bureau of Standards (NSRDS-NBS), TPRC has assumed its responsibility for the generation of Standard Reference Data on the thermophysical properties of substances and materials to meet the national needs. As a result, TPRC generates a series of reports giving recommended values of thermophysical properties of definable substances, materials, or systems. While all numerical data find their way in TPRC Data Series, these research reports discuss in detail the considerations involved in arriving at the recommended reference values with a full assessment of the experimental data and theoretical guidelines on which the critical evaluation is based. The reports are normally released by TPRC first in the form of a "preliminary report" and distributed internationally to a number of experts for review and criticism. The formal reports are then published under NSRDS auspices and released in the National Standard Reference Data Series.

TPRC's activity in this area during the first two years (1 June 1964 to 30 June 1966) was concentrated on the generation of critical tables of the thermal conductivity of specifically selected materials. This results in the following two reports:

(1) "Thermal Conductivity of Selected Materials," R. W. Powell, C. Y. Ho, and P. E. Liley, National Standard Reference Data Series - National Bureau of Standards NSRDS-NBS 8, 1-168, 1966.

A total of 29 substances and materials are studied. These are the metals aluminum, copper, gold, Armco iron, iron, manganin, mercury, platinum, platinum-rhodium (40%) alloy, silver, tungsten; the nonmetallic solids aluminum oxide, beryllium oxide, Corning code 7740 glass, diamond, magnesium oxide, Pyroceram brand glass-ceramic code 9606, quartz, thorium dioxide, titanium dioxide; and the fluids argon, carbon tetrachloride, diphenyl, helium, nitrogen, m-terphenyl, p-terphenyl, toluene, and water.

(2) "Thermal Conductivity of Selected Materials, Part 2," C. Y. Ho, R. W. Powell, and P. E. Liley, National Standard Reference Data Series - National Bureau of Standards NSRDS-NBS 16, 1-146, 1968.

A total of 16 substances and materials are studied. These are the metals cadmium, chromium, lead, magnesium, molybdenum, nickel, niobium, tantalum, tin, titanium, zinc, zirconium; the nonmetal graphite (5 species); and the fluids acetone, ammonia, and methane.

In 1967 and 1968 efforts were concentrated on the generation of critical tables of the thermal conductivity of the elements which are not covered in the above two reports. Efforts were also made to expand the tables for the elements which are in liquid or gaseous state at normal temperature and pressure to include recommended values for the solid and saturated vapor states also. This results in the following "preliminary report":

(3) "Standard Reference Data on the Thermal Conductivity of Selected Materials, Part 3," C. Y. Ho, R. W. Powell, and P. E. Liley, Thermophysical Properties Research Center Final Report on NSRDS-NBS Contract CST-1346, 1-435, 1968.

A total of 68 elements are studied. These are antimony, argon, arsenic, barium, beryllium, bismuth, boron, bromine, calcium, cerium, cesium, chlorine, cobalt, dysprosium, erbium, europium, fluorine, gadolinium, gallium, germanium, hafnium, helium, holmium, hydrogen (including deuterium and tritium), indium, iodine, iridium, krypton, lanthanum, lithium, lutetium, manganese, neodymium, neon, neptunium, nitrogen, osmium, oxygen, palladium, phosphorus, rhodium, rubidium, ruthenium, samarium, scandium, selenium, silicon, sodium, strontium, sulfur, technetium, tellurium, terbium, thallium, thorium, thulium, uranium, vanadium, xenon, ytterbium, and yttrium. For most of the nonmetallic elements which

are liquid or gaseous at normal temperature and pressure, recommended values are given for solid, saturated liquid, saturated vapor, and atmospheric-pressure gaseous states. For the other elements, recommended values are provided mainly for the solid state, though values for both solid and liquid states are given for 13 elements.

After five years of diligent effort, we have completed the critical evaluation, analysis and synthesis of the available data for the thermal conductivity of the elements across the periodic table. This five-year effort is now in the process of final review and updating, and it is anticipated that a definitive work on the program entitled "Thermal Conductivity of the Elements" will become available in 1970 under the auspices of the National Bureau of Standards, Office of Standard Reference Data.

3. MASTERS THESES IN THE PURE AND APPLIED SCIENCES

"Masters Theses in the Pure and Applied Sciences Accepted by Colleges and Universities of the United States," Beth M. Schick (Editor), Volumes I to XIII.

This work provides a unique source of information on current academic research and serves as a barometer on research trends.

This annual publication has evolved from a rather limited attempt to report masters thesis titles in five disciplines to include all the pure and applied sciences (except mathematics and the life sciences). In Volume III, an experiment was made to report doctoral dissertations as well, but this was discontinued in subsequent volumes. Because of the gradual development of this publication it has undergone some modifications of its title in the first three volumes; however, the work is now recognized as listed above. The volumes contain a table of contents and an index to the universities and colleges. A brief statistical summary of coverage is given below.

Masters Theses in the Pure and Applied Sciences

	Thesis Year	Contributing Institutions	Titles Reported
Volume I			
Part I	1955	93	1002
Part II	1956	93	1027
Volume II	1957	154	1727
Volume III*			
Part I	1958	139	3736
Volume IV	1959	162	4984
Volume V	1960	183	5708
Volume VI	1961	186	5911
Volume VII	1962	186	6321
Volume VIII	1963	175	6505
Volume IX	1964	174	6940
Volume X	1965	170	7310
Volume XI	1966	173	7099
Volume XII	1967	167	6909
Volume XIII**	1968	174	7802

*Part II of Volume III includes doctoral dissertations for 1956-57 academic year, citing 2846 titles from 103 universities.

**Effective with Volume XIII, "Masters Theses in the Pure and Applied Sciences" appears under a new cover design and represents a turning point in the twelve-year publication of this unique reference work as the Thermophysical Properties Research Center (TPRC) and University Microfilms Library Services, Ann Arbor, Michigan, join forces in its publication. As in the past, TPRC will gather the thesis titles and will prepare the manuscript for the volume while the University Microfilms will print and disseminate this work on a worldwide basis. Back volumes of the "Masters Theses in the Pure and Applied Sciences" may also be purchased from University Microfilms.

SECTION VI

CONCLUSIONS

This technical report has covered those phases of TPRC's activities which are either fully or partly funded under this contract for the period 1 January to 31 December 1969, and has also described briefly a number of related activities not under this contract. The results of this program are disseminated at large through two major publications: the Thermophysical Properties Research Literature Retrieval Guide and the TPRC Data Series.

The total efforts at TPRC are centered on the single goal of the advancement of knowledge concerning all aspects of thermophysics and thermophysical properties of materials. Comprehensiveness of treatment, compatible with the highest scientific and engineering standards, forms the basic guiding philosophy of performance. To the extent that TPRC's activities constitute a continuing systematic program, the planning of its activities is geared to both short range as well as long range goals, thus leading to effective utilization of both intellectual and fiscal resources.

APPENDIX

TABLE OF CONTENTS AND GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES OF THE FIRST SEVEN VOLUMES OF THE TPRC DATA SERIES

Volume 1. Thermal Conductivity - Metallic Elements and Alloys
- Contents
- Grouping of Materials and List of Figures and Tables

Volume 2. Thermal Conductivity - Nonmetallic Solids
- Contents
- Grouping of Materials and List of Figures and Tables

Volume 3. Thermal Conductivity - Nonmetallic Liquids and Gases
- Contents
- Grouping of Materials and List of Figures and Tables

Volume 4. Specific Heat - Metallic Elements and Alloys
- Contents
- Grouping of Materials and List of Figures and Tables

Volume 5. Specific Heat - Nonmetallic Solids
- Contents
- Grouping of Materials and List of Figures and Tables

Volume 6. Specific Heat - Nonmetallic Liquids and Gases
- Contents
- Grouping of Materials and List of Figures and Tables

Volume 7. Thermal Radiative Properties - Metallic Elements and Alloys
- Contents
- Grouping of Materials and List of Figures and Tables

VOLUME 1. THERMAL CONDUCTIVITY - METALLIC ELEMENTS AND ALLOYS

CONTENTS

MATERIAL INDEX

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

* Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

1. ELEMENTS (continued)

2. NONFERROUS BINARY ALLOYS

* Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

2. NONFERROUS BINARY ALLOYS (continued)

* Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

2. NONFERROUS BINARY ALLOYS (continued)

2. NONFERROUS BINARY ALLOYS (continued)

3. NONFERROUS MULTIPLE ALLOYS

3. NONFERROUS MULTIPLE ALLOYS (continued)

* Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

3. NONFERROUS MULTIPLE ALLOYS (continued)

4. FERROUS ALLOYS

A. CARBON STEELS

B. CAST IRONS

C. ALLOY STEELS

* Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

4. FERROUS ALLOYS (continued)

5. INTERMETALLIC COMPOUNDS

5. INTERMETALLIC COMPOUNDS (continued)

6. MIXTURES OF INTERMETALLIC COMPOUNDS

6. MIXTURES OF INTERMETALLIC COMPOUNDS (continued)

7. MISCELLANEOUS ALLOYS AND MIXTURES

VOLUME 2. THERMAL CONDUCTIVITY - NONMETALLIC SOLIDS

CONTENTS

MATERIAL INDEX

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

2. SINGLE OXIDES

*Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

2. SINGLE OXIDES (continued)

3. OXIDE COMPOUNDS

*Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

4. BINARY MIXTURES OF SINGLE OXIDES AND/OR OXIDE COMPOUNDS

4. BINARY MIXTURES OF SINGLE OXIDE AND/OR OXIDE COMPOUNDS (continued)

5. MULTIPLE MIXTURES OF SINGLE OXIDES AND/OR OXIDE COMPOUNDS

6. MIXTURES OF OXIDE AND NONOXIDE

7. IODIDE

8. BROMIDES

9. CARBIDES

10. CHLORIDES

11. FLUORIDES AND THEIR MIXTURES

12. NITRATES

13. NITRIDES

14. PHOSPHATES

15. SULFATES

16. SULFIDES AND THEIR MIXTURES

17. CERMETS

18. MISCELLANEOUS INORGANIC COMPOUNDS AND MIXTURES

19. MINERALS

19. MINERALS (continued)

20. AGGREGATE MIXES

21. MISCELLANEOUS REFRACTORY MATERIALS AND GLASSES

22. POLYMERS

*Number marked with an asterisk indicates that recommended values are also reported for this material on separate figure and table of the same number followed by the letter R.

23. MISCELLANEOUS ORGANIC COMPOUNDS

24. SYSTEMS

25. ANIMAL AND VEGETABLE NATURAL SUBSTANCES AND THEIR DERIVATIVES

25. ANIMAL AND VEGETABLE NATURAL SUBSTANCES AND THEIR DERIVATIVES (continued)

26. FABRICS, YARNS, AND HAIRS

27. PROCESSED COMPOSITES

28. PROCESSED MINERAL SUBSTANCES

29. SLAGS AND SCALES

30. RESIDUES

VOLUME 3. THERMAL CONDUCTIVITY - NONMETALLIC LIQUIDS AND GASES

CONTENTS

NUMERICAL DATA

MATERIAL INDEX

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

2. INORGANIC COMPOUNDS

3. ORGANIC COMPOUNDS

*S = solid, L = saturated liquid, V = saturated vapor, G = gas.

3. ORGANIC COMPOUNDS (continued)

4. BINARY SYSTEMS

A. Monatomic - Monatomic Systems

* L = saturated liquid, G = gas.

4. BINARY SYSTEMS (continued)

B. Monatomic - Nonpolar Polyatomic Systems

C. Nonpolar Polyatomic - Nonpolar Polyatomic Systems

*G = gas.

4. BINARY SYSTEMS (continued)

C. Nonpolar Polyatomic - Nonpolar Polyatomic Systems (continued)

D. Polar - Nonpolar Polyatomic Systems

E. Polar - Polar Systems

5. TERNARY SYSTEMS

A. Monatomic Systems

*G = gas.

5. TERNARY SYSTEMS (continued)

B. Monatomic and Nonpolar Polyatomic Systems

C. Nonpolar Polyatomic Systems

D. Nonpolar and Polar Systems

6. QUATERNARY SYSTEMS

A. Monatomic Systems

B. Monatomic and Nonpolar Polyatomic Systems

7. MULTICOMPONENT SYSTEMS

* G = gas.

VOLUME 4. SPECIFIC HEAT - METALLIC ELEMENTS AND ALLOYS

CONTENTS

NUMERICAL DATA

MATERIAL INDEX

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

1. ELEMENTS (continued)

2. NONFERROUS BINARY ALLOYS

2. NONFERROUS BINARY ALLOYS (continued)

2. NONFERROUS BINARY ALLOYS (continued)

3. NONFERROUS MULTIPLE ALLOYS

3. NONFERROUS MULTIPLE ALLOYS (continued)

4. FERROUS ALLOYS

A. CARBON STEELS GROUP I

B. CARBON STEELS GROUP II

C. ALLOY STEELS GROUP I

D. ALLOY STEELS GROUP II

4. FERROUS ALLOYS (continued)

D. ALLOY STEELS GROUP II (continued)

VOLUME 5. SPECIFIC HEAT - NONMETALLIC SOLIDS

CONTENTS

NUMERICAL DATA

MATERIAL INDEX

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

2. OXIDES

2. OXIDES (continued)

2. OXIDES (continued)

3. ANTIMONIDES

4. ARSENIDES

5. BERYLLIDES

6. BORIDES

6. BORIDES (continued)

7. CARBIDES

8. GERMANIDES

9. IODIDES

10. PHOSPHIDES

11. SELENIDES

12. SILICIDES

12. SILICIDES (continued)

13. SULFIDES

13. SULFIDES (continued)

14. TELLURIDES

15. BROMIDES

16. CHLORIDES

16. CHLORIDES (continued)

17. FLUORIDES

17. FLUORIDES (continued)

18. HYDRIDES

19. NITRIDES

20. CARBONATES

21. NITRATES and NITRITES

22. SULFATES

22. SULFATES (continued)

23. GLASSES and CERMETS

VOLUME 6. SPECIFIC HEAT - NONMETALLIC LIQUIDS AND GASES

CONTENTS

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

2. INORGANIC COMPOUNDS

3. ORGANIC COMPOUNDS

*L = liquid, G = gas.

3. ORGANIC COMPOUNDS (continued)

4. MIXTURES

*L = liquid, G = gas.

VOLUME 7. THERMAL RADIATIVE PROPERTIES - METALLIC ELEMENTS AND ALLOYS

CONTENTS

NUMERICAL DATA

MATERIAL INDEX

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

Note: Figure number with "A" indicates analyzed data graph.
*No figure

1. ELEMENTS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

1. ELEMENTS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

1. ELEMENTS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

1. ELEMENTS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

1. ELEMENTS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

Note: Figure number with "A" indicates analyzed data graph.
*No figure

1. ELEMENTS (continued)

2. BINARY ALLOYS

Note: Figure number with "A" indicates analyzed data graph.
*No figure

Note: Figure number with "A" indicates analyzed data graph.
*No figure

3. MULTIPLE ALLOYS

Note: Figure number with "A" indicates analyzed data graph.
*No figure

3. MULTIPLE ALLOYS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

3. MULTIPLE ALLOYS (continued)

Note: Figure number with "A" indicates analyzed data graph.
*No figure

3. MULTIPLE ALLOYS (continued)

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Thermophysical Properties Research Center Purdue University West Lafayette, Indiana 47906	Unclassified 2b. GROUP

3. REPORT TITLE

A CONTINUING SYSTEMATIC PROGRAM ON TABLES OF THERMOPHYSICAL PROPERTIES OF MATERIALS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Summary Technical Report - 1 January 1969 to 31 December 1969

5. AUTHOR(S) (First name, middle initial, last name)

C. Y. Ho

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1970	116	4187

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
F33615-68-C-1229 b. PROJECT NO. 8975 c. Task No. 897502 d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFML-TR-70-92

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Air Force Materials Laboratory Air Force Systems Command Wright-Patterson Air Force Base, Ohio 45433

13. ABSTRACT

This technical report covers work in a continuing systematic program on the thermophysical properties of materials involving the literature search, acquisition, codification, and organization, and data extraction, compilation, evaluation, correlation, analysis, and synthesis, the preparation of "intermediate tables" presenting the total available experimental information, and the final preparation of internally consistent tables of "best data" referred to as "Tables of Recommended Reference Values." The work reported on consists of both data tables projects and scientific documentation efforts. The data tables projects are on the thermal conductivity, specific heat, thermal radiative properties (emittance, reflectance, absorptance, transmittance), thermal diffusivity, and thermal linear and volumetric expansion of elements, ferrous and nonferrous alloys, intermetallic, semiconducting, and nonmetallic compounds, cermets, ceramics, mixtures, composites, systems, polymers, etc., and on the thermal conductivity, specific heat, and viscosity of fluids and fluid mixtures. Property data are presented in both tabular and graphical forms, with accompanying tables giving specifications and characterizations of the test specimens for the data. The resulting data tables are disseminated at large through the 13-volume TPRC DATA SERIES published commercially. This report does not contain the completed thousands of data sheets, but does reproduce in the Appendix, the Table of Contents and the Grouping of Materials and List of Figures and Tables for each of the first 7 volumes (which contain over 8000 pages) of the TPRC DATA SERIES to show the scope of their coverage. In scientific documentation, the scope is broader. TPRC covers all materials and maintains cognizance over 16 thermophysical properties (six more than mentioned above). There are now 55700 references in TPRC's automated Information Storage and Retrieval System. The resulting information on research literature is disseminated through the THERMOPHYSICAL PROPERTIES RESEARCH LITERATURE RETRIEVAL GUIDE, published commercially.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Thermophysical Properties						
Thermal Conductivity						
Accommodation Coefficient						
Thermal Contact Resistance						
Thermal Diffusivity						
Specific Heat						
Viscosity						
Emittance						
Reflectance						
Absorptance						
Transmittance						
Absorptance to Emittance Ratio						
Prandtl Number						
Diffusion Coefficient						
Thermal Linear Expansion Coefficient						
Thermal Volumetric Expansion Coefficient						
Surface Tension						
Solids						
Liquids						
Gases						
Elements						
Metals						
Molten Metals						
Semimetals						
Semiconductors						
Nonmetals						
Graphites						
Alloys						
Intermetallics						
Compounds						
Mixtures						
Refractories						
Ceramics						
Cermets						
Composites						
Systems						
Polymers						
Coatings						
Paints						
Data Tables						
Data Compilation						
Critical Evaluation						
Data Analysis						
Data Synthesis						
Recommended Reference Values						
Standard Reference Data						
Information Storage and Retrieval System						